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Intelligent Vision System for Autonomous Vehicle Operations

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ABSTRACT

We describe a complex optical system consisting of a 4f optical correlator with programmable filters under control of a digital on-board computer that operates at video rates for filter generation, storage, and management.

ROBOTIC PLANETARY EXPLORATIONS

Exploration of an unknown environment has traditionally required human presence to classify the environment and the objects within it, and to make survival decisions on the basis of input to the senses.

Planetary exploration to such destinations as Mars and the Moon, however, is to an environment unfriendly to human habitation. It is not only physically demanding, it also represents an operational challenge to maintain life support and protection systems. The obvious advantage of using an intelligent machine for exploration is protection of human life in a potentially adverse environment.¹ Additionally, a machine is self-sufficient in an environment that does not support biological life. An artist's conception of a roving vehicle exploring the Martian surface is shown in Figure 1.

A semi-autonomous vehicle with locomotion, visual and tactile sensors, and some on-board intelligence is capable of surveying large surface areas to locate suitable landing, habitat, and operations center sites, and to perform preliminary geological investigations prior to human exploration. This exploratory vehicle may be equipped with a combined vision-image classification system based on optical correlator technology.² The application of the correlator to the object-recognition task is illustrated in Figure 2.

OPTICAL CORRELATOR SYSTEM

The optical correlator system consists of four modules: the scene coherent-light conversion module; the optical correlator bench; the matched filter module; and a stand-alone on-board digital computer for filter storage, management, and on-board filter generation. Figure 3 is a photograph of the optical correlator system. Figure 4 shows the two personal computers that are used to operate the correlator system. The first one is used for filter management and control. The other is dedicated to the tracking function of the correlator.

Capabilities

Using the optical correlator system to navigate the semi-autonomous vehicle on an uncharted planetary surface requires the following capabilities:

- a) Recognition of objects (object clusters and features)
- b) Recognition of rotated and magnified objects
- c) Recognition of objects upon change of perspective
- d) In-situ generation of reference filters

Optical correlator system

The optical correlator performs the basic function of recognizing an object when the matched filter has been generated with prior knowledge. The 4f configuration incorporated in this system, shown in Figure 5, is based on the classical Vander Lugt correlator.³ An actual photograph of the correlator optical system is shown in Figure 6. It was designed as a laboratory prototype instrument for ease of adjustment and as a test bed for further optimization. More compact optical correlators can be built once the technology has been demonstrated in the laboratory environment.⁴

Scene input is presented in coherent light to the Fourier transform lens group, consisting of a positive Fourier transform (FT) lens and a negative Fourier transform Barlow lens. M3 is a beam-turning mirror which, like all the other mirrors, fits the optical correlator on a standard 24- by 48-inch optical table.

The Fourier transform of the scene is obtained on the surface of the liquid crystal light valve after the polarized beam passes through the polarizing beam-splitter cube. A programmable video display is used to project the matched filter on the liquid crystal light valve.

The liquid crystal light valve in the filter module reflects at those pixel locations where a video display and the scene Fourier transform have a bright pixel at the same time. The reflected light is polarized, so the beam splitter reflects it into the correlation arm. An imaging correlation lens images the surface of the liquid crystal light valve on the CCD camera after two more beam-turning mirrors. A binarizing polarizer is used to increase contrast between dark and light pixels.

Incoherent light from the scene is translated into coherent light in the input arm of the optical correlator by using a video display—liquid crystal light valve combination with the HeNe laser beam as the read beam. A video camera provides video input to the display, which is coupled to the liquid crystal light valve using a fiber optics faceplate. A properly conditioned laser beam, after passing through a spatial filter for clean-up, an aperture for beam limiting, and a collimating lens, uniformly illuminates the spatial light modulator. The input scene in coherent and polarized light is transmitted through the beam splitter and fed into the optical correlator.

Rotation and magnification

A Vander Lugt optical correlator recognizes an object and finds its location in the same orientation and same size as the object used for generating the matched filter. In this correlator system, a CRT display is used for addressing the liquid crystal spatial light modulator. Thus, the rotated and magnified object can be recognized by derotating and demagnifying the input scene on the CRT raster using auxiliary electronics.

Perspective change

Perspective change for a slowly moving exploratory vehicle is not expected to be appreciable. It will be treated as a linear combination of a small magnification change as the vehicle approaches the object and a small rotational change as the vehicle moves past the object.

In-situ filter generation

The video camera may be used to capture the image of an object under new conditions, such as an appreciable change in illumination or a change in perspective. The scene is stored on the frame

grabber. The object may be isolated and a new matched filter generated using the on-board computer. The object coordinates can be recalled from the on-board computer or relayed to the mobile vehicle by a remote human operator.

Filter management and control

The optical correlator system is flexible in recognizing objects because it uses binary phase-only filters⁵ as matched filters. Thus, only zero or one is stored for each pixel position, requiring only 525 x 525 memory locations. Only the central 33 percent of the filter frame is used, because the higher frequencies have not been found to contain much information. This further reduces memory requirements. Such small memory usage, combined with video rates of filter recall, results in a correlator that possesses a large repertoire of matched filters that can be recalled at video rates.

APPLICATIONS TO PLANETARY EXPLORATIONS

Figure 7 shows a hypothetical Martian surface as seen by a camera on board the roving vehicle. The rover is pursuing a route among rocks. It has been previously instructed to make a left turn after the dark rock on the left by a communication orbiter.

The autonomous vehicle uses the dark rock (outlined) to generate a binary phase-only matched filter, as shown in Figure 8. The correlation peak is shown in Figure 9 for a 0° viewing angle. When the autonomous vehicle turns at the rock, the correlation intensity decreases. At 10° rotation to the left of normal, the peak is attenuated, as shown in Figure 10. Although the peak intensity appears the same here due to the photographic process, the noise becomes more prominent, decreasing the signal-to-noise ratio. Figure 11 shows the relative correlation peak intensity as a function of rotation angle for the dark rock. With an increase in rotation angle beyond 10°, a decrease in the correlation intensity requires generation of a new matched filter of the dark rock.

CONCLUSION

The hybrid digital-optical cross correlator is highly suitable for image recognition and feature classification in support of semiautonomous robotic explorations.

ACKNOWLEDGMENTS

The author wishes to thank Jan Ralls of the Jet Propulsion Laboratory for encouragement and helpful discussions. The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the Research Directorate of the U.S. Army Missile Command in Redstone Arsenal, Alabama.

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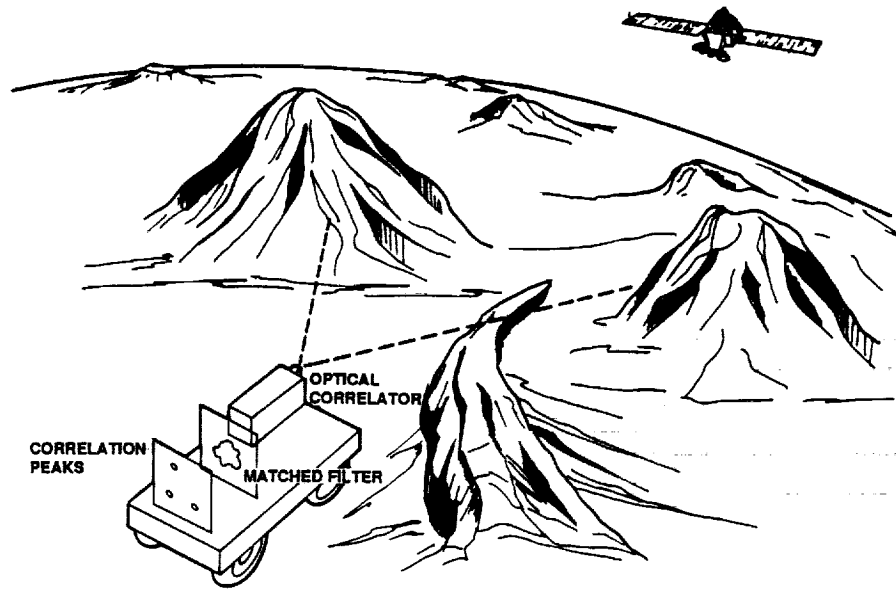


Figure 1. Artist's conception of a roving vehicle exploring the Martian surface

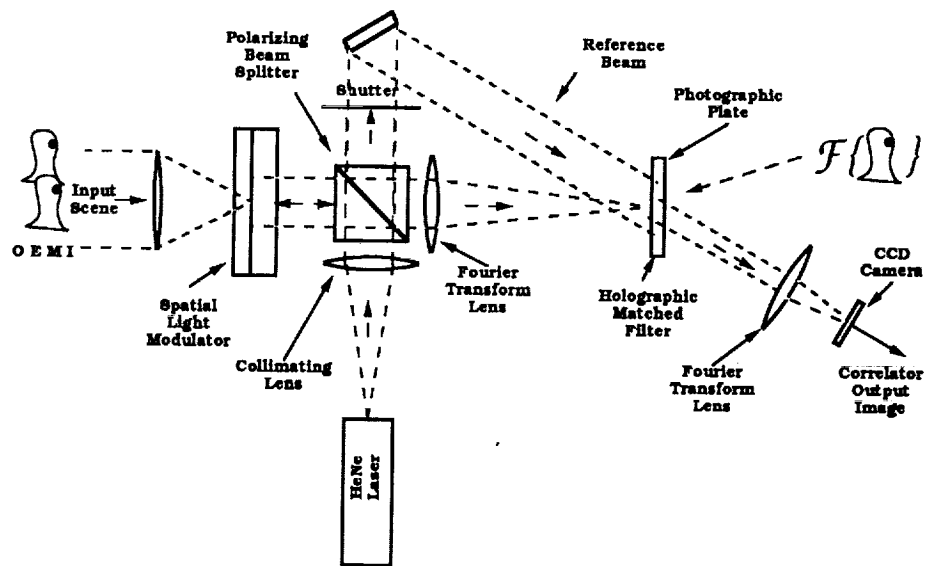


Figure 2. Correlator technology applied to object recognition

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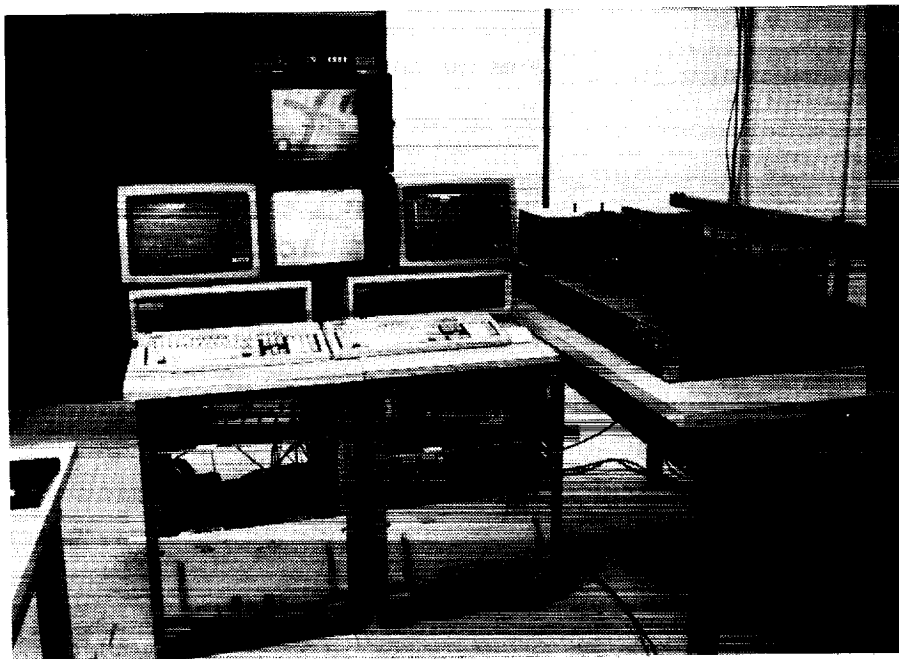


Figure 3. Photograph of the optical correlator system

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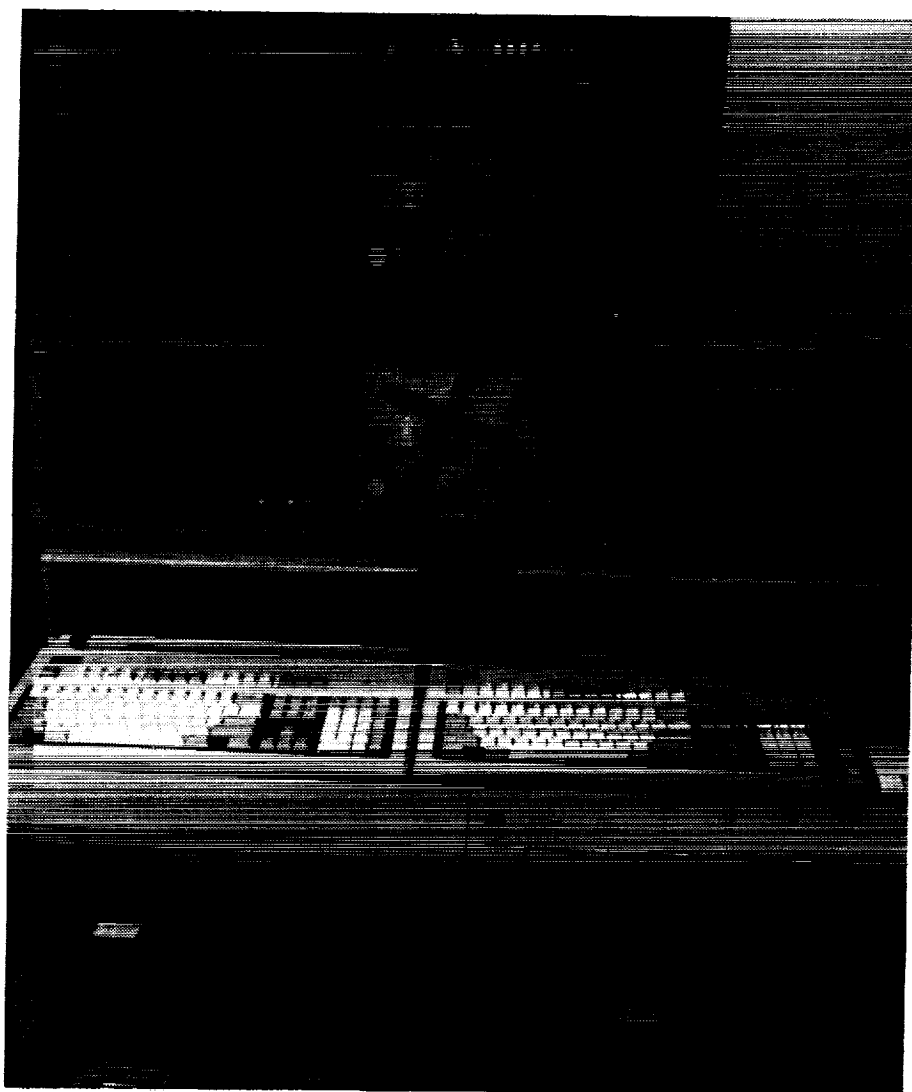


Figure 4. Photograph of the PC computers used for filter management and object tracking

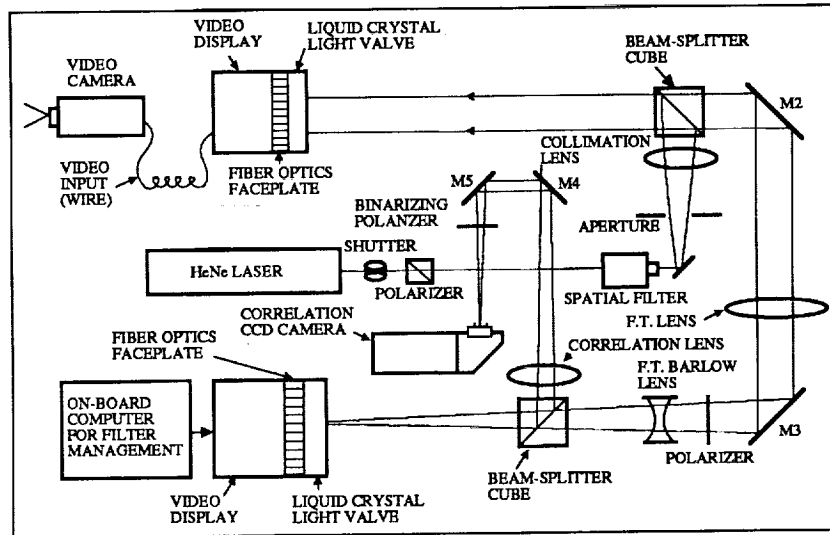


Figure 5. Schematics of the correlator optical system

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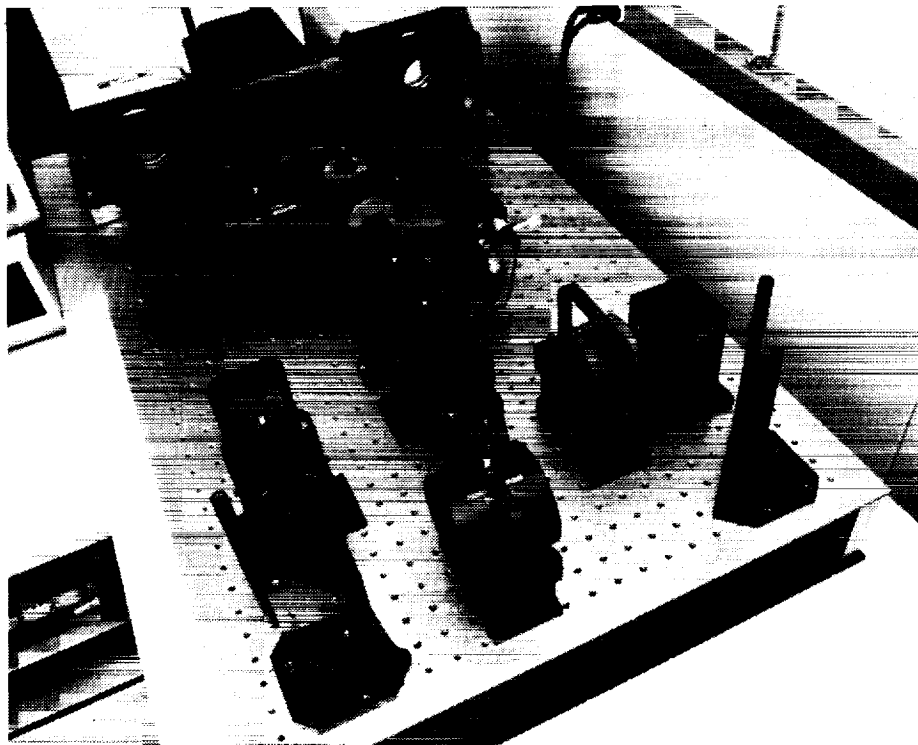


Figure 6. Photograph of the correlator optical system

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Figure 7. Hypothetical Martian surface as seen by on-board camera on the roving vehicle

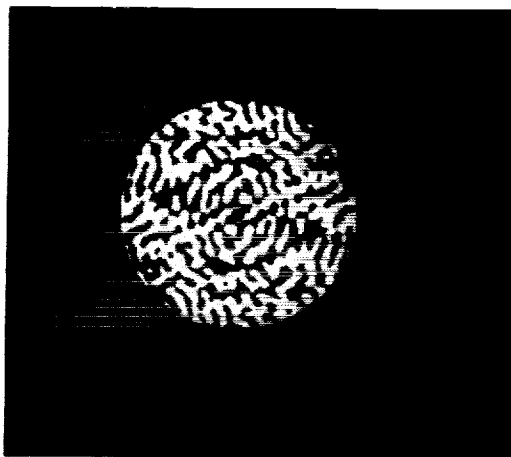
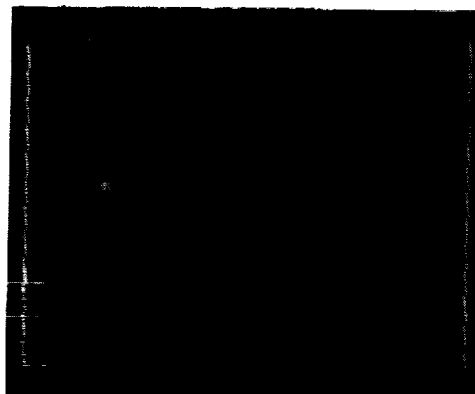


Figure 8. Binary phase-only filter of the dark rock on the left side of Figure 7



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Figure 9. Correlation peak due to recognition of dark rock - direct view

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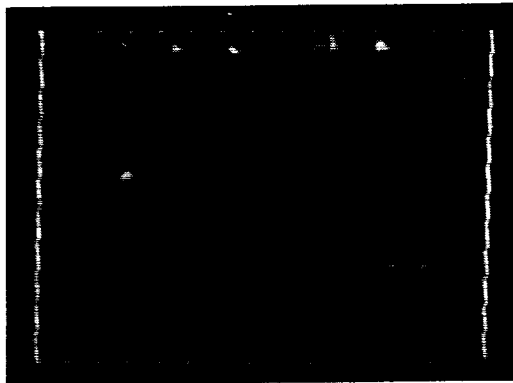


Figure 10. Correlation peak due to recognition of dark rock at- 10 degree rotation

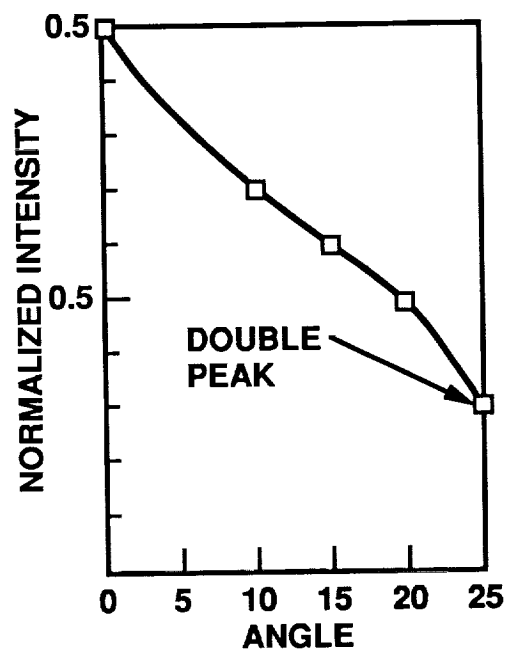
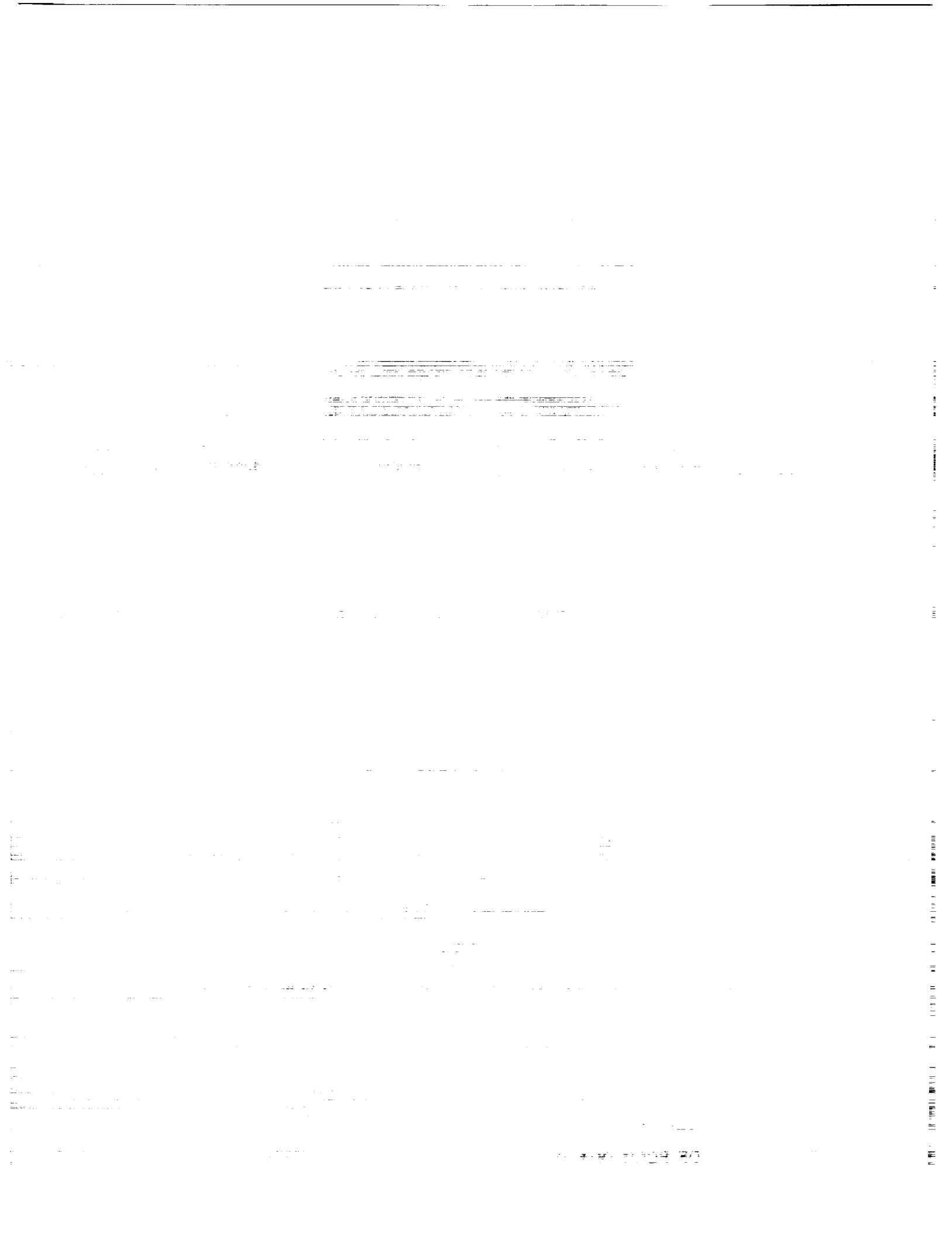


Figure 11. Relative peak intensity of the correlation peak as a function of rotation angle

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